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**Activated Carbon Filter Bed Efficiency
at the Nitro, West Virginia Water
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ACTIVATED CARBON FILTER BED EFFICIENCY
AT THE NITRO, WEST VIRGINIA WATER FILTRATION PLANT

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16. Abstracts On September 17, 1968 three high-flow carbon adsorption method (CAM) samplers were installed at the Nitro, West Virginia Water Filtration Plant of the West Virginia Water Company. The purpose of the sampling program was threefold; one, to check the efficiency of the activated carbon filter bed in the removal of organic compounds as indicated by Carbon Chloroform Extract (CCEhf) and carbon alcohol extract, two, to determine the length of time that highly effective removal of organics would occur; and three, to investigate the relationship between CCEhf and threshold odor during this type of treatment.			
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INTRODUCTION

Nitro, West Virginia obtains its water supply from the Kanawha River. This surface water supply has considerable chemical pollution that causes severe taste and odor problems. The water is treated by high pressure aeration followed by the conventional water treatment processes of chemical coagulation, flocculation, sedimentation and filtration. In this instance, the sand in the filters has been replaced by activated granular carbon to provide additional treatment for the reduction of organics and/or taste and odor.

On September 17, 1968 three high-flow carbon adsorption method (CAM) samplers were installed at the Nitro, West Virginia Water Filtration Plant of the West Virginia Water Company. One sampled the coagulated and settled influent to the carbon bed filter. Another sampled the effluent from the activated carbon filter No. 8 which had been reactivated and returned to service September 17, 1968. Filter No. 8 remained in operation throughout the length of this study. The third CAM sampler was placed to sample the combined finished water from all the filters in the plant.

PURPOSE

The purpose of the sampling program was threefold; one, to check the efficiency of the activated carbon filter bed in the removal of organic compounds as indicated by Carbon Chloroform Extract (CCE_{hf})* and carbon alcohol extract (CAE_{hf})*;

*The subscript "hf" indicates the method used for collection and extraction of the organic matter in the water. For this study the high flow method was used.

two, to determine the length of time that highly effective removal of organics would occur; and three, to investigate the relationship between CCE_{hf} and threshold odor during this type of treatment.

PROCEDURE

The water was passed through the carbon adsorption method (CAM) sample column for sampling periods of 2 weeks per sample. The flow-through rate was regulated by an orifice flow-rate control device as described by Taylor², et al. This flow control allows approximately 1/4 gallon per minute (~ 950 milliliters per minute) to flow through the sampler. No volume throughput recording device is involved, so an estimate of the throughput must be made from volume versus time measurements at least once each day. The CCE analyses were made according to Standard Methods,³ high-flow method.

The CAM samples were collected by the Nitro Water Filtration Plant personnel under the supervision of Mr. Edward Dean and shipped to the Cincinnati Laboratory, Bureau of Water Hygiene, currently, Water Supply Programs Division, OWP, for CCE_{hf} and CAE_{hf} determination. Threshold odor tests are performed routinely by Mr. Dean and his staff and their data are used in this study.

RESULTS

Sample Volume

The flow rate through the CAM samplers varied from 600 to 1200 milliliters per minute. The lower flow rates occurred in the filter bed influent sampler, see Column 4, Table 1, because the orifice and the carbon in the sampler clogged with particles that had not been removed during sedimentation. The clogging of the orifice of this CAM sampler was eliminated by installation of an intake screen of 40-mesh stainless steel. Small particles passed through the screen and orifice, partially clogging the carbon in the sampler, causing decreased flow rates after a sample column was in use for a few days. No clogging occurred in the other two samplers that received filtered water.

Carbon Chloroform Extract (CCE_{hf}) and Carbon Alcohol Extract (CAE_{hf})

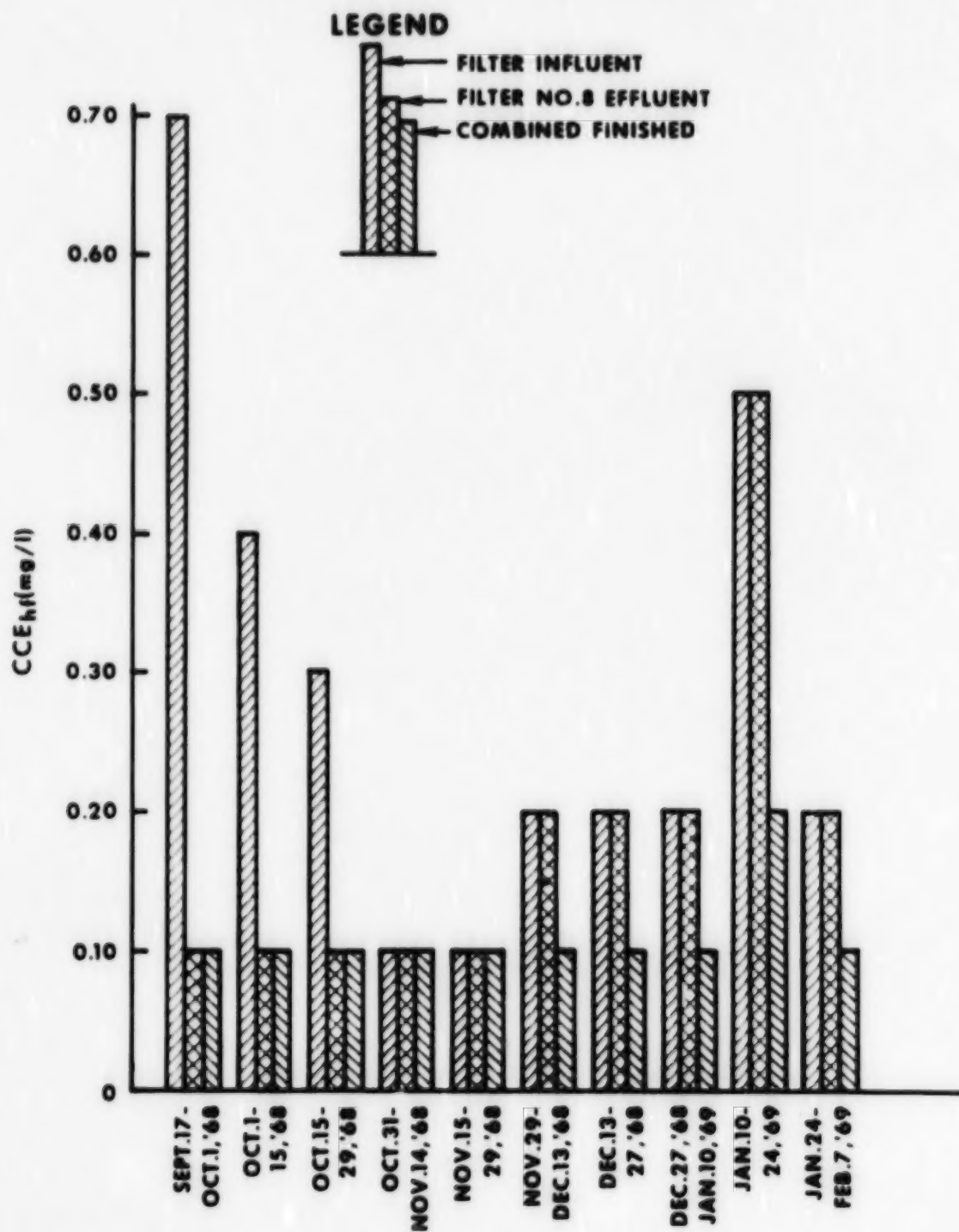
Table 1 summarizes the CCE_{hf} and CAE_{hf} data collected during this study. Although this type of data are often reported to three significant figures, the precision of the test does not warrant this practice. Therefore, in this report the data will be reported to one significant figure. Figure 1 indicates that carbon bed Filter No. 8 was effective in the removal of CCE_{hf} only during its first six weeks of service. By the sixth week, when Filter No. 8 was exhausted, it had adsorbed about 120 pounds of CCE_{hf} material, which is only 0.0023 lbs CCE_{hf} /lb of carbon in bed.

During weeks 7-10, no removal of CCE_{hf} occurred, but the effluent from Filter No. 8 was no worse than the combined effluent because of the improvement of the influent water quality. For the rest of the period (Nov. 29, 1968 - Feb. 7, 1969), the CCE_{hf} of Filter No. 8 effluent was approximately that of the filter

Table 1. Carbon Chloroform Extract and Carbon Alcohol Extract Sample Results

Date of Sample	Week	Sample Source	Sample Volume (liters)	CCE _{hf} mg/l	CAE _{hf} mg/l	Remarks
9/17 - 10/1/68	1,2	Filter Influent	16,330	0.7	0.3	
		Filter #8 Eff.	21,980	0.1	0.1	
		Comb. Finished	19,085	0.1	0.1	
10/1 - 15/68	3,4	Filter Influent	22,670	0.4	0.2	
		Filter #8 Eff.	21,560	0.1	0.1	
		Comb. Finished	21,980	0.1	0.1	
10/15 - 29/68	5,6	Filter Influent	20,690	0.3	0.2	
		Filter #8 Eff.	18,550	0.1	0.2	
		Comb. Finished	22,030	0.1	0.1	
10/31 - 11/14/68	7,8	Filter Influent	20,780	0.1	0.3	Pump off and on due to over-heating. Accurate estimate of flow impossible.
		Filter #8 Eff.	22,360	0.1	0.2	
		Comb. Finished	22,410	0.1	0.1	
11/15- 29/68	9,10	Filter Influent	15,925	0.1	0.3	Orifice required daily cleaning.
		Filter #8 Eff.	21,200	0.1	0.2	
		Comb. Finished	20,410	0.1	0.2	
11/29 - 12/13/68	11,12	Filter Influent	17,930	0.2	0.1	
		Filter #8 Eff.	17,660	0.2	0.3	
		Comb. Finished	23,640	0.1	0.2	
12/13 - 27/68	13,14	Filter Influent	17,550	0.2	0.3	Impeller on pump replaced when pump failed.
		Filter #8 Eff.	18,870	0.2	0.2	
		Comb. Finished	21,185	0.1	0.2	
12/27 - 1/10/69	15,16	Filter Influent	16,750	0.2	0.2	
		Filter #8 Eff.	22,050	0.2	0.2	
		Comb. Finished	22,270	0.1	0.2	
1/10 - 24/69	17,18	Filter Influent	15,230	0.5	0.2	End plate on pump replaced when pump failed. Impeller on pump replaced when pump failed.
		Filter #8 Eff.	21,340	0.5	0.2	
		Comb. Finished	15,425	0.2	0.2	
1/24 - 2/7/69	19,20	Filter Influent	16,080	0.2	0.3	
		Filter #8 Eff.	15,705	0.2	0.3	
		Comb. Finished	21,100	0.1	0.1	

FIGURE 1
CARBON CHLOROFORM EXTRACT



influent and higher than that of the combined finished water, because newly reactivated filters were replacing exhausted ones elsewhere in the plant.

The very high CCE_{hf} of the filter influent at the time Filter No. 8 was put into service, 0.7 mg/l, might have caused the rapid exhaustion of this filter for CCE_{hf} removal. With some of the filters being removed from service and being replaced by reactivated ones, the combined finished water CCE_{hf} concentration was often less than that of Filter No. 8. The schedule of filter operation shown in Table 2 prevented the finished water from exceeding the 1962 Public Health Service Drinking Water Standards⁴ (DWS) for CCE_{hf} (0.2 mg/l) during weeks 17 and 18 when the effluent from Filter No. 8 exceeded the DWS.

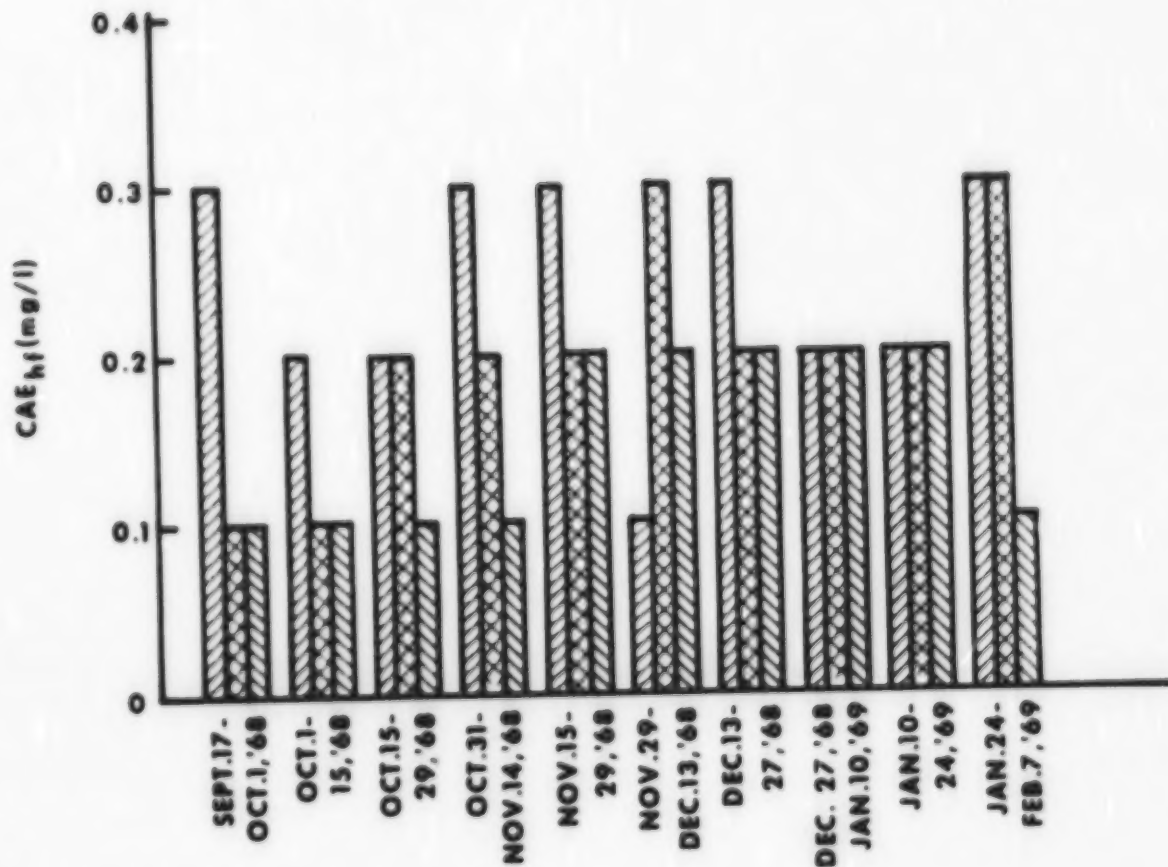
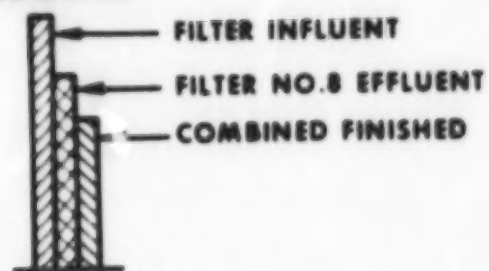
Figure 2 presents the CAE_{hf} data given in Table 1. This figure shows that carbon bed filter No. 8 was effective in CAE_{hf} removal during its first fourteen weeks of service, except for weeks 5 - 6, and weeks 11 - 12, when no removal occurred. During this study the CAE_{hf} of the combined finished water varied between 0.1 and 0.2 mg/l. While the 1962 DWS does not contain a standard for CAE, these concentrations are fairly low.

Table 2. Record of Filters Used During Period of Sample Collection.
(Note: All Carbon Reactivated at Least Once.)

Filter No.	Record of Filter Run		Days	Last Three Threshold Odor Numbers
	Started	Ended		
11	1/9/68	10/31/68	296	12,13,10
16	1/15/68	1/15/68	0	
13	1/21/68	12/30/69	345	8,5,5
14	1/25/68	12/20/69	331	4,5,6
12	6/29/68	Still Operating at End of Study		
17	6/26/68	"		
18	7/4/68	"		
19	7/9/68	"		
20	7/18/68	"		
8	9/17/68	"		
9	11/1/68	"		
15	12/21/68	"		
11	12/28/68	"		
16	1/9/69	"		
14	1/13/69	"		

FIGURE 2
CARBON ALCOHOL EXTRACT

LEGEND



Odor

During the time of the study the raw water threshold odor (T.O.) ranged from 100 to 250 and averaged 180. The T.O. is substantially reduced by aeration. During late 1963, high pressure aeration reduced raw water TO about 75 percent. The threshold odor record of Filter No. 8 effluent in Table 3 showed no odor for the first 2 weeks of operation, at ^{which time} / an odor of 1 was detected. This odor level continued through weeks 3-10, an odor of 2 being detected after 71 days of operation.

After six weeks the capacity of Filter No. 8 to remove CCE_{hf} was exhausted, but the T.O. was only about 1 at ^{weeks 17,18.} this time. This occurred even though the DWS was exceeded only during / ^{week} From the sixth/ the filter effluent odor gradually increased, exceeding the DWS after 18 weeks, while the carbon filter bed continued to remove little, if any CCE material.

The pattern for the removal of CAE materials was somewhat different. CAE material was removed by Filter No. 8 several weeks longer than CCE material, and the exhaustion of this removal capacity at 14 weeks more closely corresponded to the odor breakthrough (T.O. = 4) at 18 weeks, although the performance of the activated carbon bed with respect to CAE removal is somewhat confusing during weeks 5 - 6 and 11 - 12.

These comparisons do indicate, however, that the effectiveness of removal of CCE and CAE, especially CCE, is rather short-lived when compared to the period of odor control. Odor control by the activated carbon is effective for a much longer time, although the

Table 3. Threshold Odor Record for Filter No. 8

Date	No. Days in Service	Threshold Odor Number (T.O.)	Removal Efficiency	
			CCE _{hf} * %	CAE _{hf} * %
Sept. 20, 1968	3	0		
27	10	0	86	67
Oct. 1	14(2 weeks)	1		
10	23	1	75	50
16	29(4 weeks)	1		
25	38	1	67	0
31	44(6 weeks)	0		
Nov. 6	50	1	0	33
15	59(8 weeks)	1		
22	66	1	0	33
27	71(10 weeks)	2		
Dec. 5	79	2	0	Neg.
13	87(12 weeks)	2		
20	94	2	0	33
26	100(14 weeks)	2		
1969 Jan. 2	-	-	0	0
8	113(16 weeks)	3		
17	122	3	0**	0
23	128(18 weeks)	4**		
29	134	4**	0	0
Feb. 7	143(20 weeks)	4**		
14	150			
22	158(22 weeks)	3		
27	163	2		
Mar. 6	170	4**		
14	178	5**		
22	186	5**		

*For the inclusive 2-week period.

**Effluent exceeded 1962 Public Health Service Drinking Water Standards.

carbon does not provide complete odor removal during the entire period.

To show whether or not the behavior of Filter No. 8 with respect to odor removal was typical of the other filters in the plant T.O. vs. time data were collected for the other filters and are shown in Figure 3. The number of days each filter had been in operation on September 17, 1968, when Filter No. 8 was put into service is also noted on this figure. The filters in service at this time vary from 260 days of operation for Filter No. 16 to one day for Filter No. 8. The T.O. of individual filter effluents varies from zero for the newly started filter to 7, with an average of about 3.7. The effluent odor patterns of the other filters, especially Nos. 17, 18, 19 and 20 show that Filter No. 8 performed in a typical way.

The influence of blending and chlorination is shown in Figure 4. Here, the average of the T.O.'s of all individual filter effluents is shown along with the T.O. of the postchlorinated finished water. The finished water generally exhibits a higher T.O. than the filter effluent although both were greater than the 1962 Drinking Water Standards. This is most likely attributable to chlorine compounds formed during postchlorination.

Influence of Influent Water Quality on Carbon Bed Performance

In an effort to show the influence of influent water quality on the performance of activated carbon beds, T.O. data from six of the eleven filters shown in Figure 3 have been replotted in

FIGURE 3
THRESHOLD ODOR RECORD OF INDIVIDUAL FILTERS

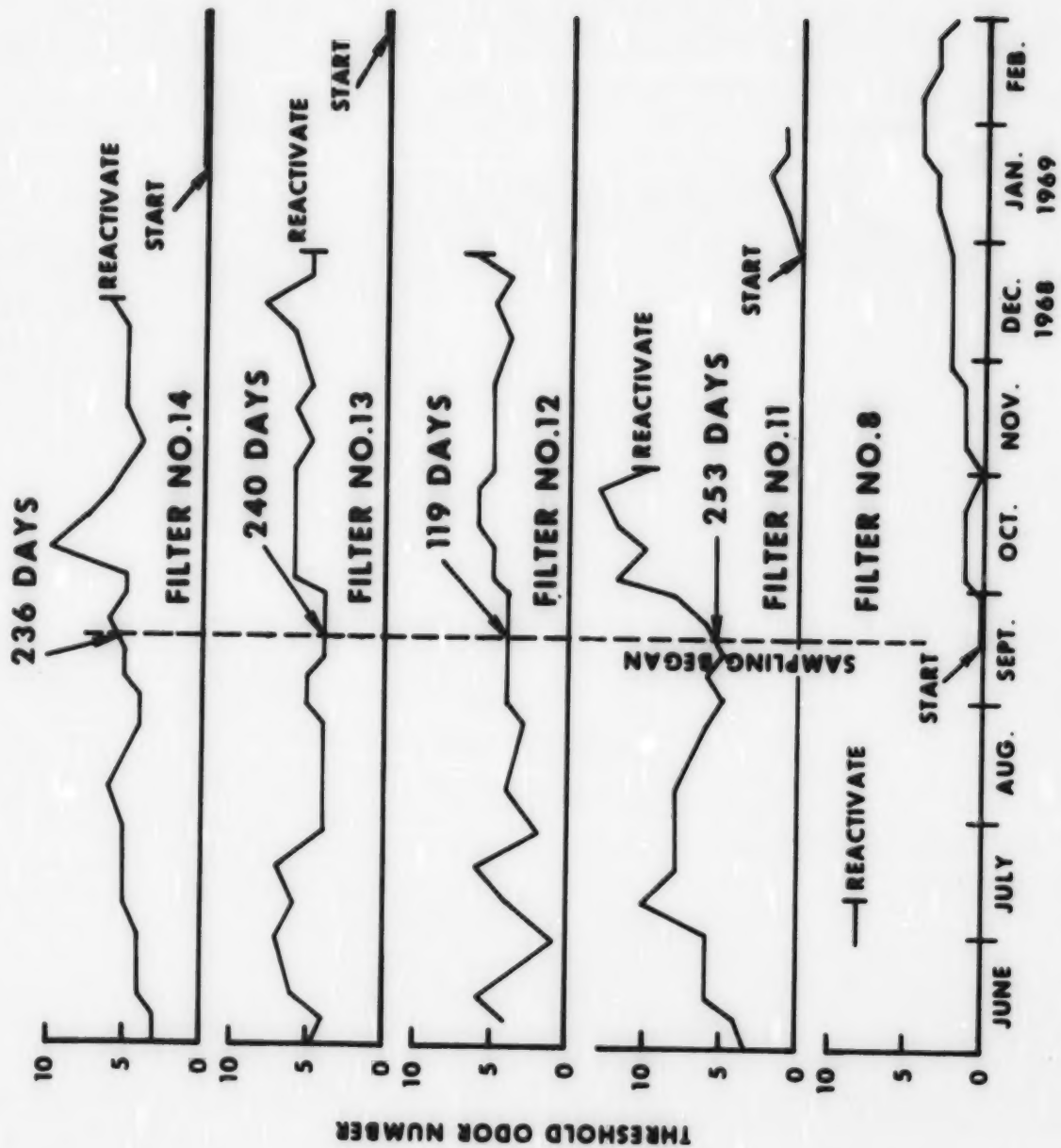


FIGURE 3 (CONTINUED)
THRESHOLD ODOR RECORD OF INDIVIDUAL FILTERS

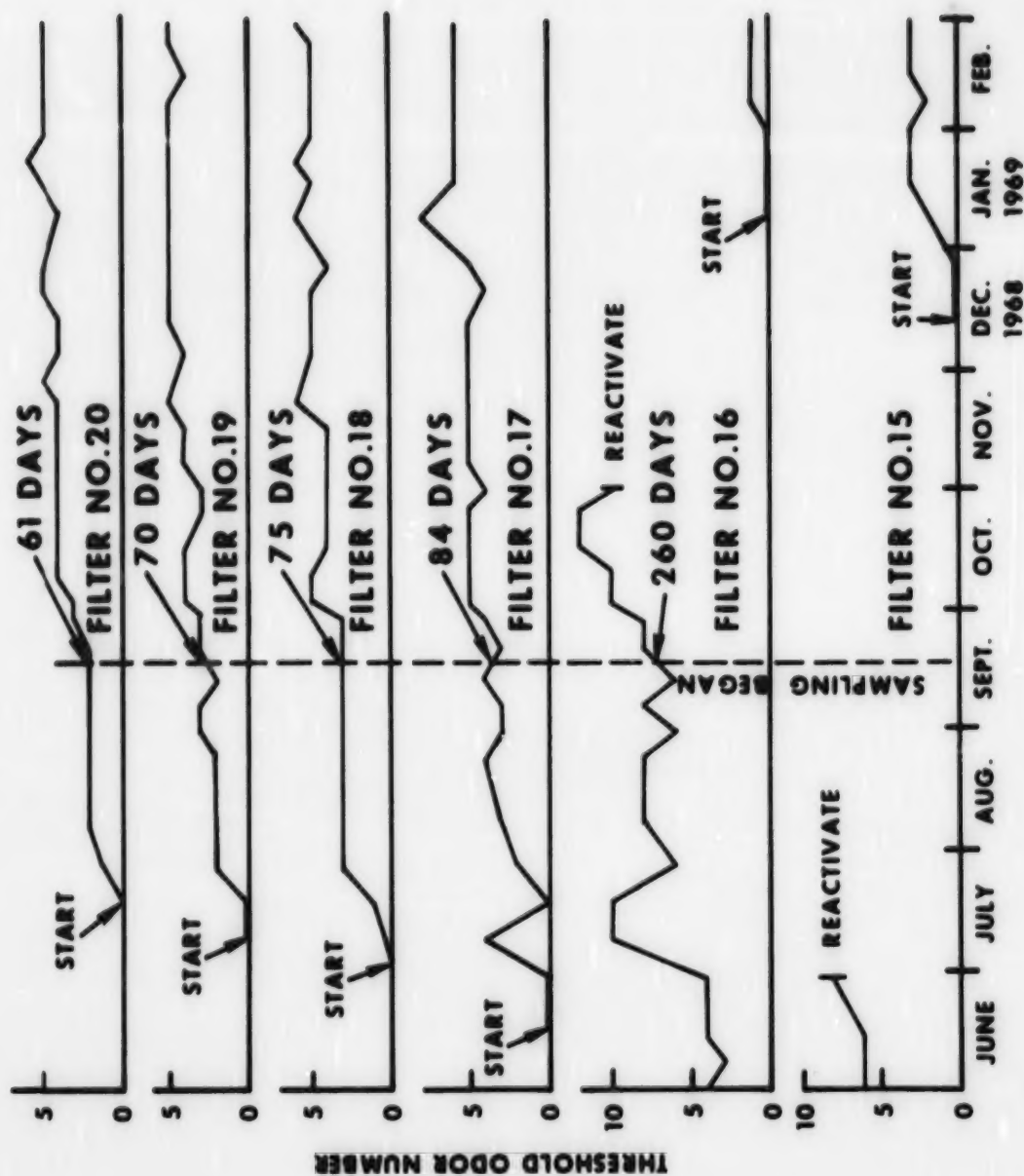


FIGURE 4
THRESHOLD ODOR OF THE POSTCHLORINATED FINISHED
WATER AND THE AVERAGE OF THE FILTER EFFLUENTS

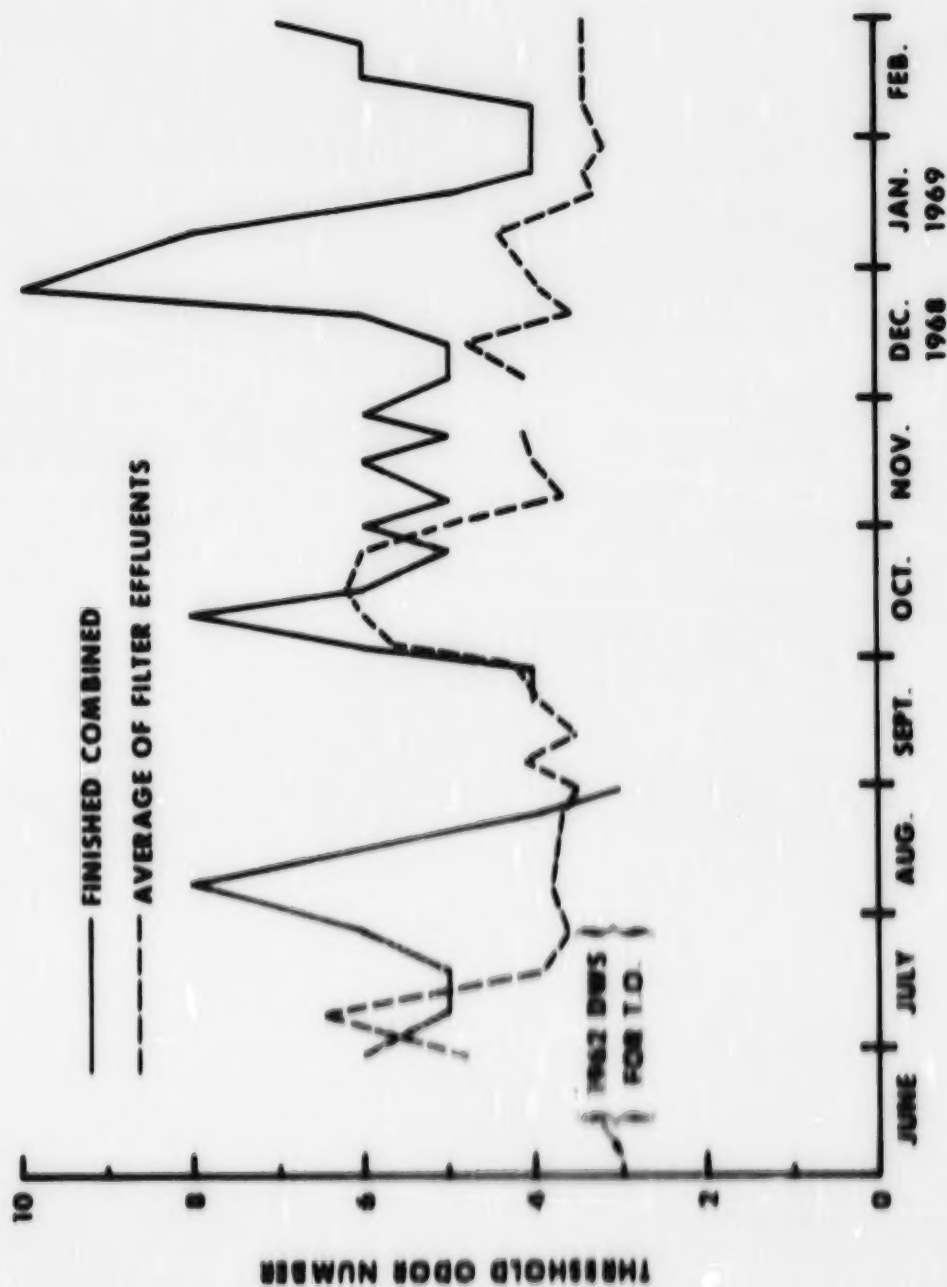
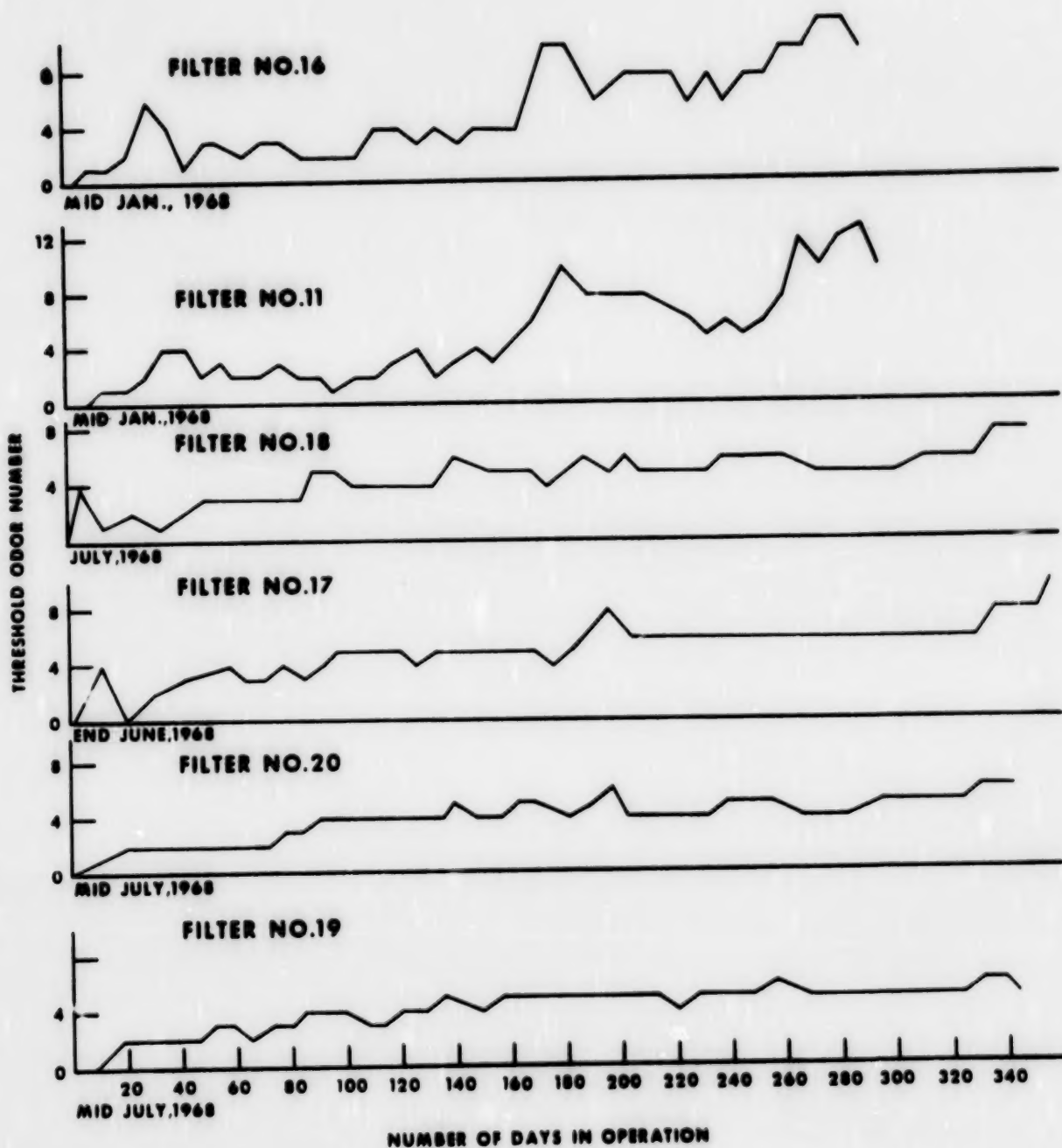


Figure 5. Here, the effluent T.O. data from 4 filters, Nos. 17, 18, 19 and 20, which were restarted during the period late June to mid-July, 1968 are compared to similar data from Filters No. 11 and 16, which were restarted about 6-1/2 months earlier. The character of the water most definitely is shown to affect the performance of the filters regarding odor control. Except for the early T.O. peaks for Filters 17 and 18, which were started shortly before 19 and 20, these four filters performed remarkably similarly. Filters 11 and 16, which were operated through a different time period show trends in T.O. passage quite like each other, but much different than Nos. 17, 18, 19 and 20. Although organic load data are not available for the first six months of 1968, something was present in the water during that period that was absent subsequently, as shown by the high threshold odors passing Filters 11 and 16 for the last half of their operation. There is no doubt, therefore, that the performance of individual filters must be evaluated on T.O. removal or some other criteria, not on number of days in operation.

FIGURE 5
THRESHOLD ODOR RECORD OF INDIVIDUAL FILTERS
BY NUMBER OF DAYS IN OPERATION



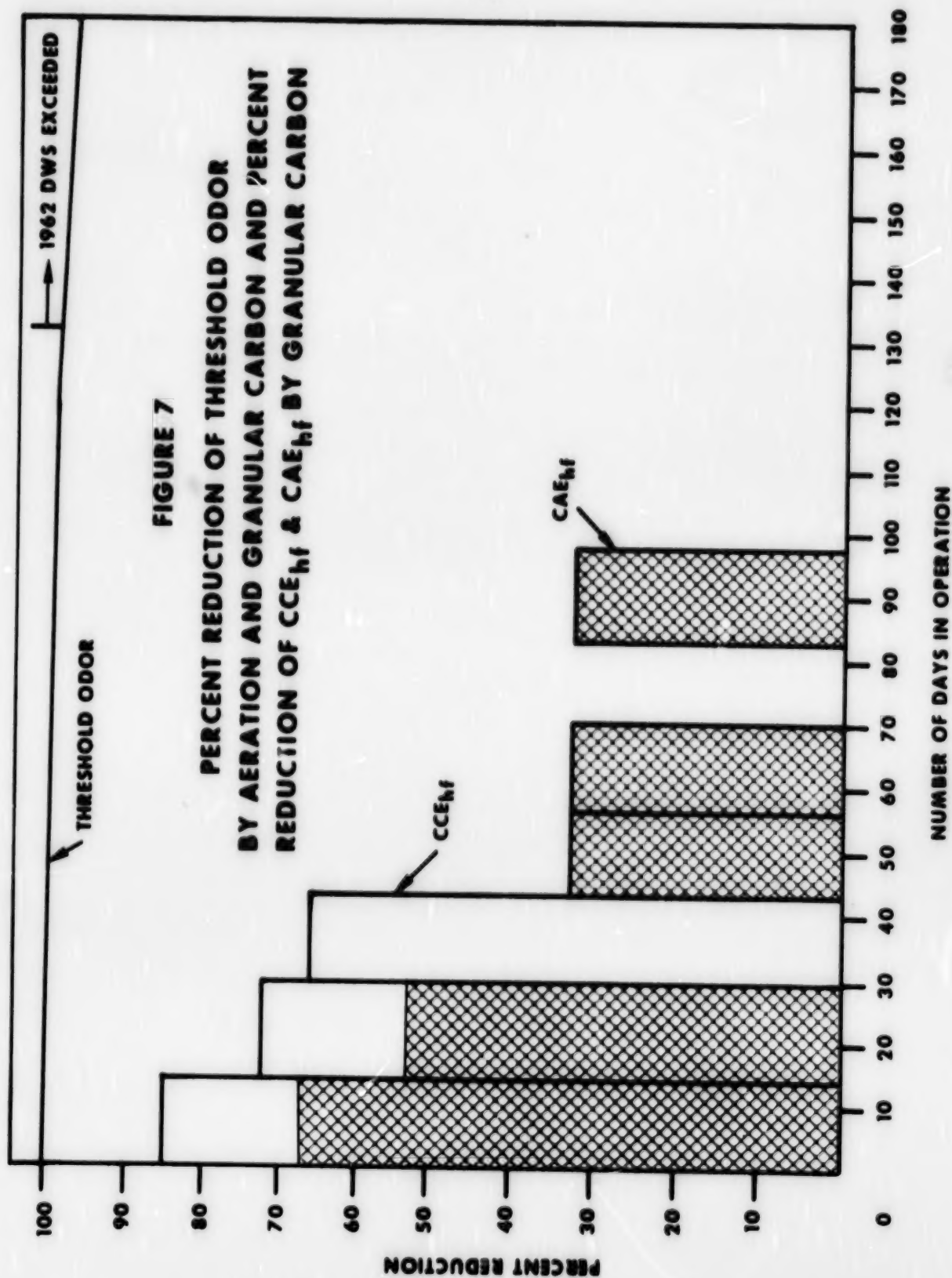
CCE_{hf} and CAE_{hf} as a Monitoring Parameter

Activated carbon beds are often installed in a water treatment plant for the control of taste and odor. Because the determination of threshold odor number is a difficult and subjective test, the suggestion has been made that monitoring the effluent from carbon beds for CCE and/or CAE might be an acceptable method for evaluating the activated carbon beds performance with respect to odor removal.

The incorrectness of using CCE_{hf} and CAE_{hf} as a measure of the capacity of an activated carbon bed for the removal of odorous materials is clearly shown in Figure 7. Here, Filter No. 8 was exhausted for the removal of CCE materials after 42 days and was exhausted for the removal of CAE materials after 98 days. High percentage removals of threshold odor were still occurring after 180 days in this filter, although the T.O. of the filter effluent exceeded the level prescribed in the 1962 Drinking Water Standards after about 128 days. Therefore, the determination of CCE_{hf} and CAE_{hf} cannot be used as a method for monitoring the odor performance of an activated carbon bed.

Organic Removal

Although, as stated above, activated carbon beds are included in water treatment plants for the control of tastes and odors, the removal of general organic material, often toxic in nature, is also a worthwhile goal. If the latter is the objective, the monitoring of the activated carbon bed effluent for organic content is essential, and the beds should be reactivated as soon as their capacity for removing CCE and/or CAE type materials is exhausted.



Cost Estimates for Granular Carbon Treatment

In an attempt to show the relative cost to meet the objectives of either odor control or organic matter control, the following calculations were made based on the data collected in this experiment.

Threshold Odor

If the operating goal is a filtered water with a ^{maximum} a/T.O. = 3, the filter operation time before reactivation would be approximately 120 days. If the allowable T.O. is 5, the time of operation would be about 180 days. The cost for the granular carbon portion of this control is found in Table 4.

TABLE 4
Cost of Granular Carbon Reactivation for Threshold Odor Control

Target Threshold Odor No.	Days of Operation to Reach This T.O.	Volume of Water Filtered (1000 gal.)	Cost of Reactivation of Carbon in One Filter ^a	Cost of Reactivation Carbon in One Filter per 1000 gal. ^a
3	120	124,860	\$1,025	\$0.008
5	180	191,420	\$1,025	\$0.005

a - The cost of reactivation is based on an estimated cost of \$0.02 per pound of carbon reactivated. The filter beds contain about 51,250 lb. of granular carbon. This cost of reactivation does not include initial construction costs, maintenance, insurance and taxes which would not be expected to exceed \$0.01 per pound of carbon reactivated. Inclusion of this cost would increase the above costs by 50 percent.

The data in Table 4 shows how staggering filter operation and blending water can reduce costs. The danger in this practice is, however, that if some exhausted filters are always on line, protection against passing a severe odor load is reduced. In addition, the intensification of odor caused by chlorination of water containing organics should not be overlooked when judging individual filter performance.

Carbon Chloroform Extract

The CCE_{hf} in the effluent from this individual filter (No. 8) exceeded the U. S. Public Health Service Drinking Water Standards⁴ of 0.2 mg/l CCE during weeks 17 and 18, but the effluent of this filter combined with that of seven to nine other filters, some of which had been in operation for a shorter time than No. 8 always satisfied the DWS. If Filter No. 8 had been reactivated when exhausted, the cost of organic removal is presented in Table 5.

TABLE 5

Cost of Granular Carbon Reactivation for Organic Removal

Days of Operation Before Exhaustion	Volume of Water Filtered (1000 gal.)	Cost of Reactivation in One Filter ^a	Cost of Reactivation in One Filter ^a per 1000 gal ^a
42 (CCE)	44,100	\$1,025	\$0.023 ^b
98 (CAE)	102,900	\$1,025	\$0.009 ^b

a - The cost of reactivation is based on an estimated cost of \$0.02 per pound of carbon reactivated. The filter beds contain about 51,250 lb. of granular carbon. This cost of reactivation does not include initial construction costs, maintenance, insurance and taxes which would not be expected to exceed \$0.01 per pound of carbon reactivated.¹ Inclusion of this cost would increase the above costs by 50 percent.

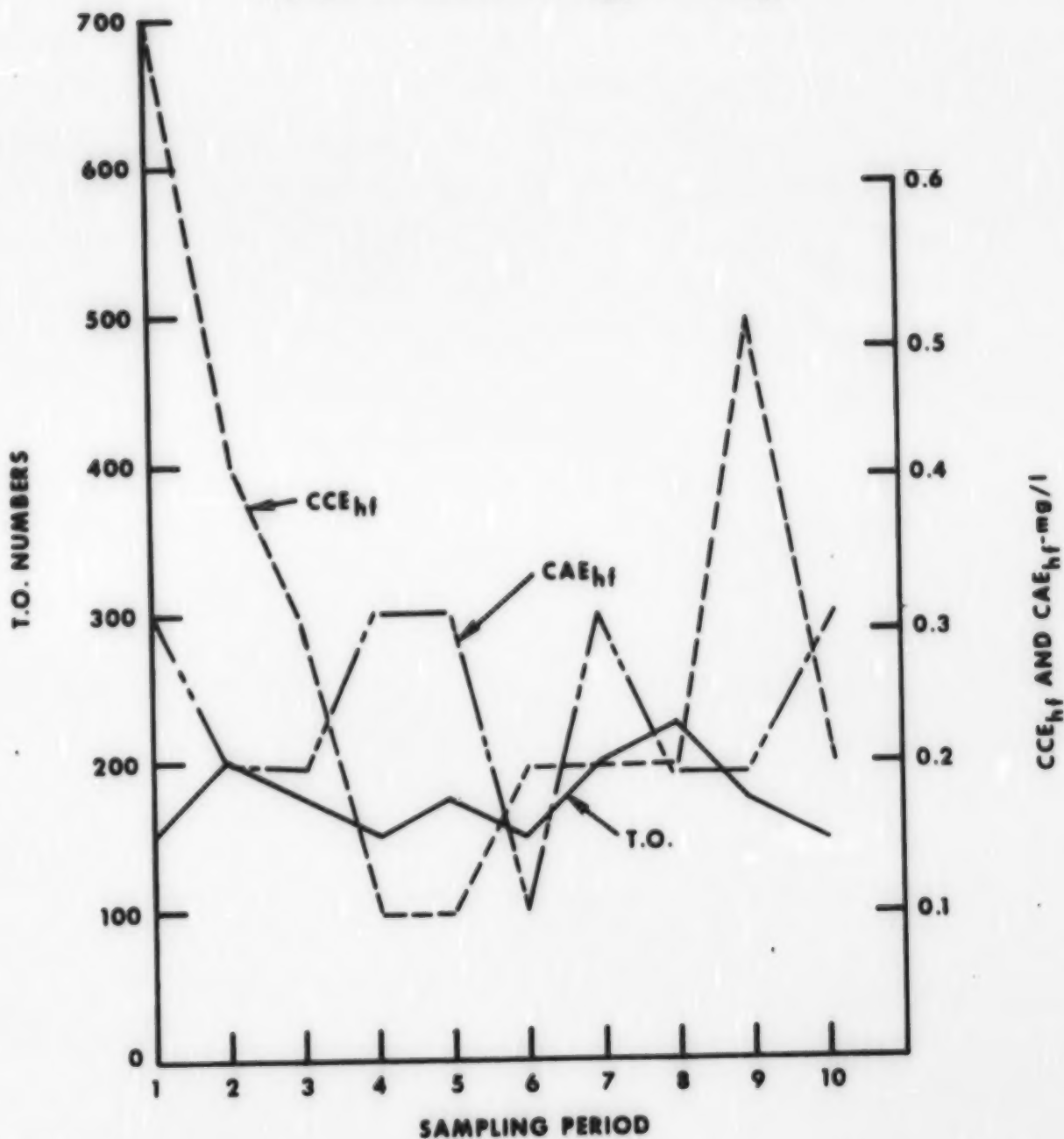
b - Costs could be reduced and some degree of organic removal maintained if the activated carbon filters were operated longer and staggered. By having some exhausted filters on line at all times, however, the possibility of passing some organics that cannot be adequately diluted does exist.

The raw water must exceed the Drinking Water Standards before the cost of removing CCE to meet the standard becomes relevant. Many waters that have severe taste and odor problems do not approach CCE_{hf} concentrations of 0.2 mg/l and thus will always meet this standard regardless of treatment. For instance, in this water, the filter influent exceeded the Drinking Water Standards in only 4 out of the 10 sampling periods. In such instances, the determining factor would be acceptable taste and odor control. Therefore, taste and odor control regulates the use of activated carbon in most water treatment. If, however, the removal of organic matter is desirable, the activated carbon bed effluents should be monitored for organic content and reactivated when exhausted.

Raw Water TO and Filter Influent CCE and CAE

To further explore the relationship, if any, between CCE_{hf} and CAE_{hf} and odor, an attempt was made to correlate raw water threshold odor with concentrations of CCE_{hf} and CAE_{hf} going onto the filters. While these measurements were taken at different places in the treatment plant, the raw water TO was probably proportional to the filter influent TO, see Figure 2(a) and 2(b) of Reference 1. Figure 8 shows that in this water, the variations in filter influent CCE_{hf} and CAE_{hf} was independent of the raw water TO and the same was probably true of the filter influent TO. This further demonstrates the importance of monitoring the parameter in question and not depending on monitoring supposedly related parameters.

FIGURE 8
ESTIMATED AVERAGE OF RAW WATER
THRESHOLD ODOR FOR 2 WEEK AND SAMPLING PERIOD.
FILTER INFLUENT CCE_{hf} & CAE_{hf}



Other Methods of Monitoring

Standard Methods³ suggests an alternate CAM sampler for the determination of the concentration of CCE-type material. This device uses a lower flow rate through the sampler and the resultant extracts are called CCE_{1f} and CAE_{1f} . While this is a better monitor, the CCE_{1f} values obtained cannot be related to the 1962 Drinking Water Standards

Snider⁵ monitored his activated carbon beds with the low-flow CAM sampler, obtaining results similar to this investigation. One difference occurred between this study and that one, however. At Piqua, Ohio, once the activated carbon beds were exhausted for CCE_{1f} and CAE_{1f} removal, cycles of desorption followed by more adsorption occurred. While this was not detected in this study, it might have been if the low-flow CAM sampler had been used. Cycles of desorption and adsorption after exhaustion have also been reported by Woodward, Dostal, and Robeck.⁶

A third method for monitoring organic matter in water is currently (1971) under development by the authors and their associate, Mr. J. Keith Carswell. This method uses a miniaturized and simplified CAM sampler and a well-defined, vigorous extraction procedure. The resulting data, called CCE_m and CAE_m is a better reflection of the / ^{actual organic content in the sample} than either the high- or low-flow CAM sampler methods. Use of this monitor at other plants in the future should further confirm the differences in organic matter removal and odor control by granular activated carbon that was experienced in this study.

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CONCLUSIONS

A study over a five-month period at Nitro, West Virginia has produced the following conclusions:

1. Granular^{activated}/carbon filters provide satisfactory taste and odor control for a considerable time after they are ineffective for CCE_{hf} and CAE_{hf} removal. Further, effluent Threshold Odor Numbers and CCE_{hf} and CAE_{hf} concentrations are generally unrelated.
2. Because odor control performance of the granular activated carbon filters is related to the quality of the influent water, reactivation should be based on odor breakthrough and not on the number of days of operation.
3. The lack of relationship between the parameters Threshold Odor Number and CCE_{hf} and CAE_{hf} concentrations was further demonstrated by the absence of correlation between raw water T.O. and the filter^{influent CCE_{hf} & CAE_{hf}} / hf .
4. To maintain protection for the consumer, activated carbon beds should be reactivated more often to maintain their organic and odor removal capacity.
5. The reactivation costs for one filter for odor, CCE_{hf} , and CAE_{hf} control respectively were calculated to be \$0.008/1000 gal., \$0.023/1000 gal., and \$0.009/1000 gal. These costs could be reduced by staggering filter operation as done in this plant and blending, but this practice may permit the passage of a high level of contaminant that cannot be effectively diluted and/or may cause odors when chlorinated.

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The permission of the West Virginia Water Company to monitor the granular carbon filter beds at Nitro, West Virginia and the collection of the samples by Mr. Edward Dean, Supervisor of the Nitro Filtration Plant are appreciated. The authors also wish to thank Messrs. Earl F. McFarren and Robert J. Mills for provision of the CCE_{hf} and CAE_{hf} data.

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